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NIMBUS 1
AUTOMATIC PICTURE TRANSMISSION (APT) TV-CAMERA SYSTEM

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Technology Directorate

July 1966

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Greenbelt, Maryland

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INTRODUCTION

The automatic picture transmission (APT) system was designed for real-time broadcast of daytime meteorological television pictures, in a format suitable for facsimile reproduction, to anyone who had the necessary ground station equipment, thus providing meteorologists with cloudcover pictures of their immediate area within a few minutes of the time they were taken.

The APT system was flown on Nimbus A (designated Nimbus 1 on achievement of orbit), the first of a series of meteorological satellites launched August 28, 1964, at the Western Test Range (WTR), Vandenberg Air Force Base, California. The orbital performance of Nimbus 1 has been discussed in detail by Press (1965). During the 371-orbit active lifetime of Nimbus 1 (August 28 to September 24, 1964), the APT system performance was highly satisfactory and response from the scientific community around the world was enthusiastic. The APT system transmitted 6999 minutes of video (about 2000 pictures) to APT ground stations throughout the world. The APT station at Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, received 36 orbits of information and recorded 88 frames of pictures. The Nimbus 1 Users' Catalog (1965) summarized the APT data obtained from that mission.

Nimbus C (Nimbus 2), the Nimbus 1 backup launched May 15, 1966, carries an APT system modified for direct transmission of nighttime infrared cloudcover pictures to specially equipped APT ground stations.

The Nimbus 1 APT system has been discussed in some detail in articles by Butler (1964, 1965); by Cowan and Hubbard (1963); by Holmes and Hunter (1964); by Hunter (1962); by Hunter and Rich (1964); by Stampfl and Press (1962); and by Stampfl and Stroud (1963). The present paper is a general description of the Nimbus 1 APT system with a detailed analysis of APT camera performance in flight as illustrated in pictures received by the APT ground stations.

NIMBUS 1 SYSTEM CHARACTERISTICS

The National Aeronautics and Space Administration (NASA) began in 1960 to develop the Nimbus program as a meteorological satellite system capable of meeting the research and development needs of the nation's atmospheric scientists and weather services. The program envisioned the development of a complete system, including:

- An amply powered earth-oriented spacecraft capable of supporting a variety of experiments designed for observation of the earth's atmosphere and for rapid transmission of the collected data

- An orbit providing worldwide coverage on a daily basis for prolonged periods of time

- A launch vehicle able to place the spacecraft into the required orbit with a high degree of reliability

- A ground-command and data-acquisition system to control the spacecraft in orbit, and to receive data

- A sophisticated ground data-processing and transmission system to provide the users (meteorologists and atmospheric physicists) with information in a convenient and meaningful form within an appropriate timescale.

A spacecraft which met the foregoing objectives was designed, built, and prepared for flight, a reliable launch vehicle was selected, and a ground complex to support the mission was constructed and placed into operation.

Spacecraft Configuration

Nimbus 1 is an earth-oriented three-axis-stabilized spacecraft which consists of three major elements (Figure 1). A 56-inch diameter sensory ring, which is a hollow circular section (torus) composed of 18 rectangular modular bays, houses the major electronic and mechanical components needed to operate the meteorological subsystems. The lower surface of the ring provides mounting space for the basic meteorological sensors recording atmospheric phenomena, such as global television picture coverage of daytime cloudcover, and measurements of infrared and reflected radiation and of the earth's heat balance. A

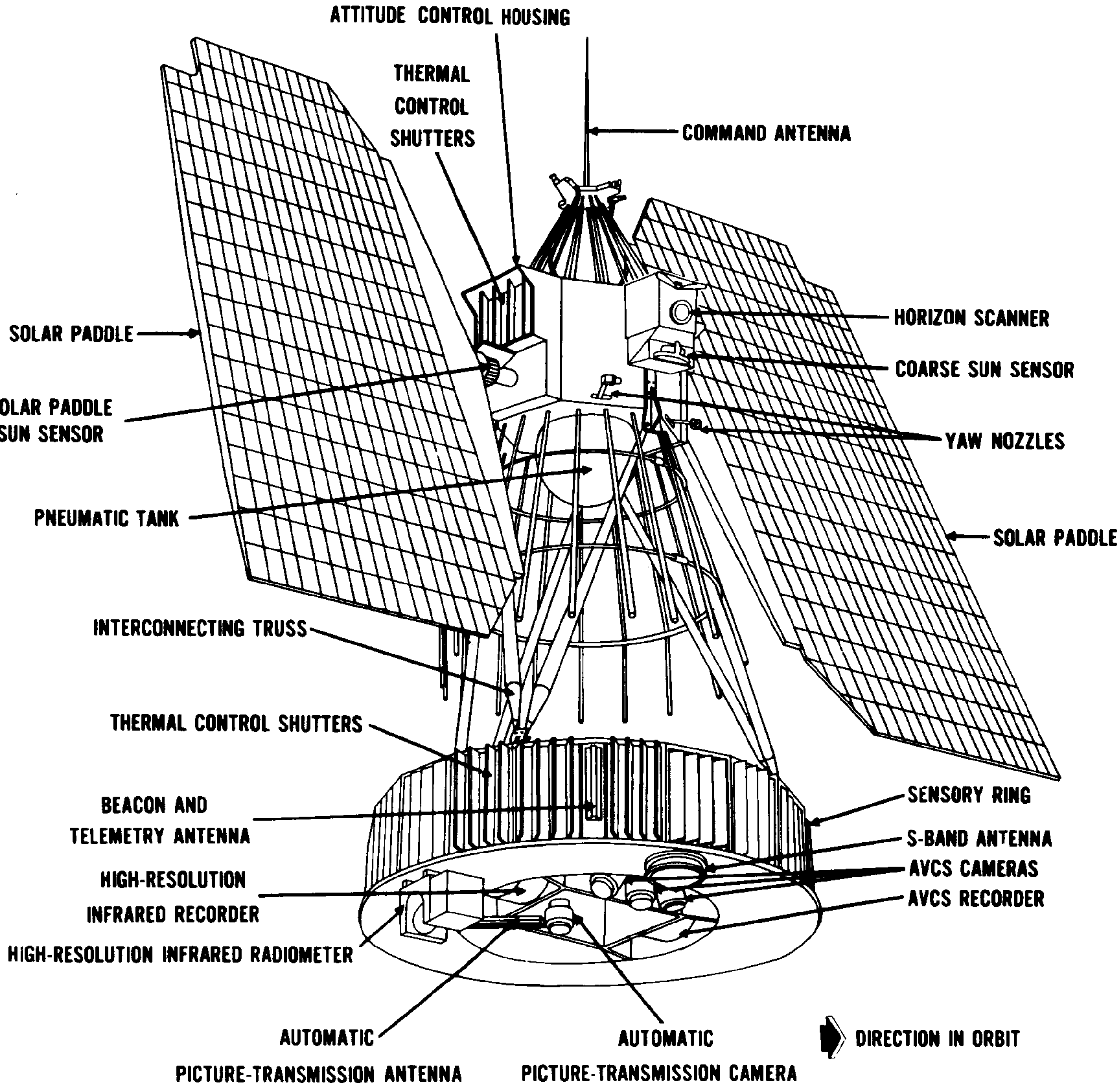

Figure 1. Nimbus 1 Spacecraft

smaller hexagon-shaped upper section, attached to the sensory ring by a truss structure, houses the attitude-control system which orients and stabilizes the spacecraft with respect to the earth and the orbit plane, and orients the solar paddles with respect to the sun. The two solar-oriented paddles, which rotate to face the sun continuously during the sunlit portion of the orbit, supply power for spacecraft operation.

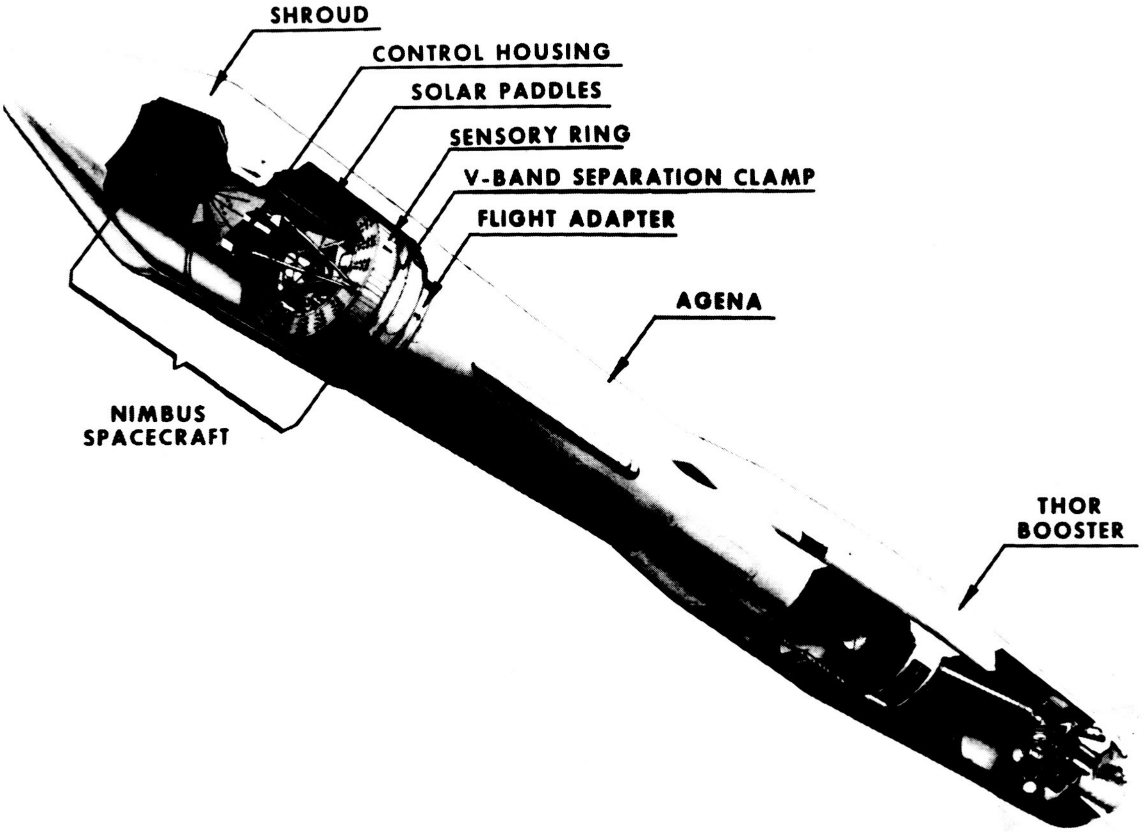

Figure 2. Thor-Agena B-Nimbus Launch Configuration

Nimbus 1 was launched into orbit on a Thor-Agena B. Figure 2 shows the spacecraft mounted on the vehicle in the launch configuration. The spacecraft is covered by a protective shround during launch.

Orbit Selection

A circular near-polar sun-synchronous orbit having an inclination of 81 degrees retrograde to the equator (Figure 3) and an altitude of 579 nautical miles was selected for sensor design. The earth's rotational movement constitutes the mechanism for longitudinal coverage, and the spacecraft's orbital travel provides latitudinal coverage. The choice of an 81-degree angle from the equator results in an orbital drift corresponding exactly to that of the earth's movement around the

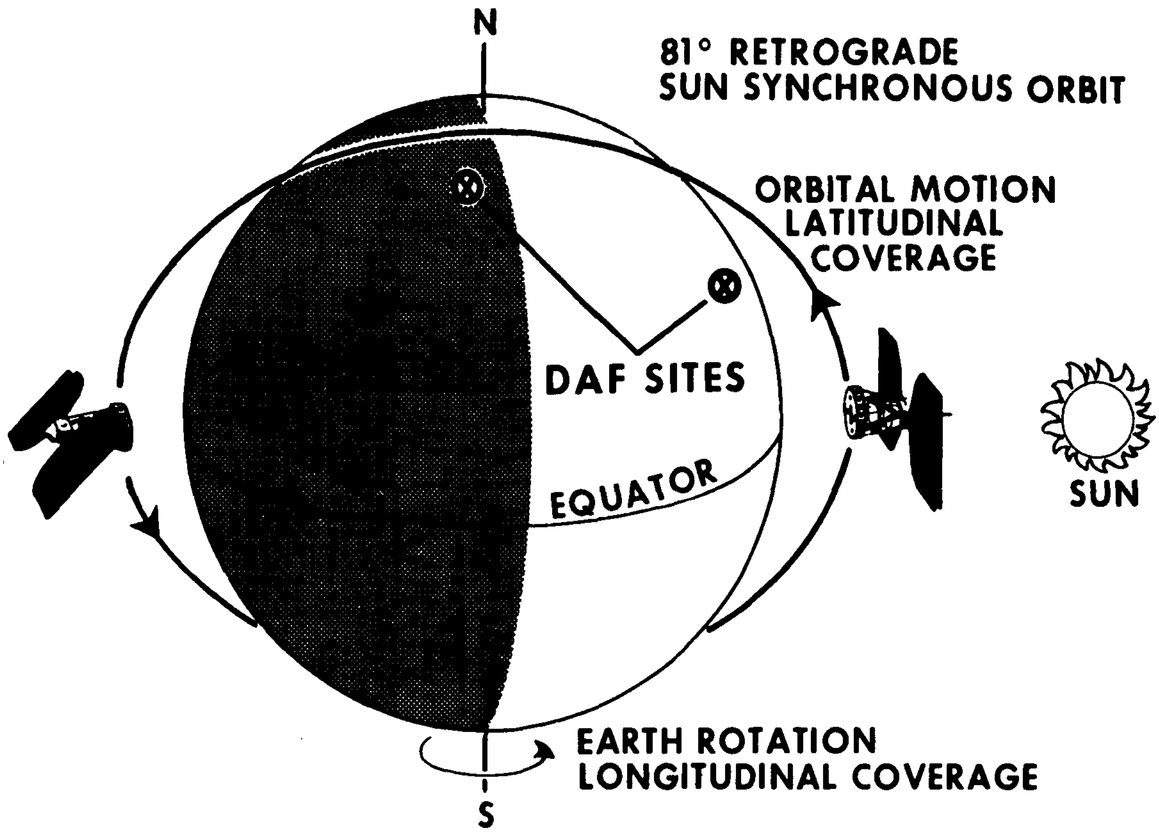

Figure 3. Nimbus High-Noon Sun-Synchronous Orbit

sun, thereby keeping the earth-sun line in the orbital plane. Thus, the solar paddles need rotate about only one axis to maintain a sun-oriented position. The chosen launch time provides a daytime equatorial crossing at local noon ("high noon"). The resulting high-noon sun-synchronous orbit provides the best picture-lighting condition for the television sensors.

An orbital period of 103 minutes yields between 13 and 14 orbits per day, permitting the data-acquisition facility (DAF) near Fairbanks, Alaska (ULASKA), to acquire data from 10 of the 13 orbits. A second DAF at Rosman, North Carolina (ROSMAN), supplements ULASKA. Wide-band microwave links transmit the data immediately to Goddard Space Flight Center (GSFC) at Greenbelt, Maryland, and to the weather services.

Because of a short second burn of the Agena vehicle, Nimbus 1 achieved an elliptical orbit with a 579-nautical-mile apogee and a 263-nautical-mile perigee instead of the desired 576 nautical miles planned (Figure 4). The initial perigee occurred at 20° N latitude on the dark

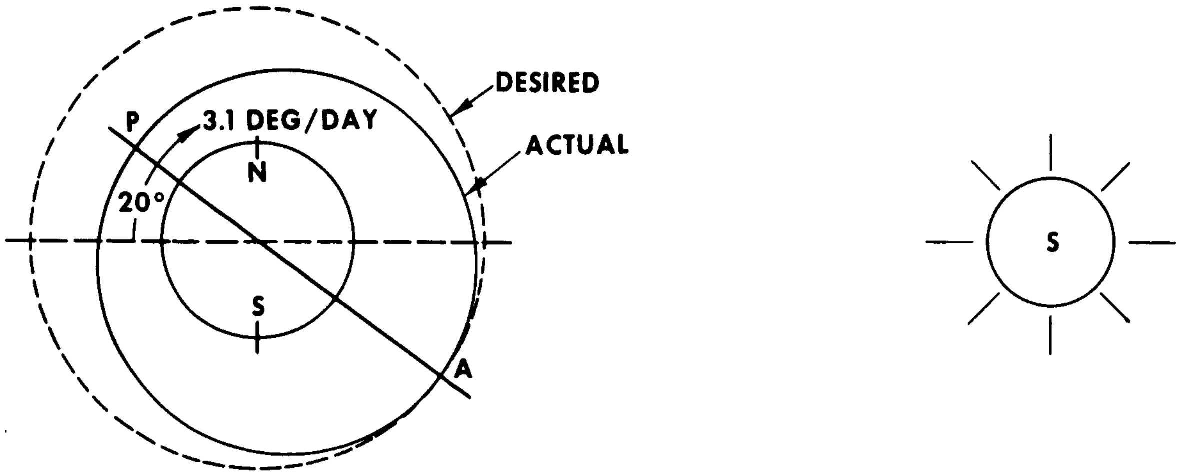

Figure 4. Nimbus 1 Orbit

side of the earth and moved northward at 3.1 degrees per day. Orbital inclination was 98.7 degrees. The anomaly in the orbit did not seriously compromise the major mission objectives. Details of the Nimbus 1 performance have been described by Huston and Press (1964), and by Press (1965).

AUTOMATIC PICTURE TRANSMISSION (APT) SYSTEM

The APT system combines instantaneous readout of real-time television pictures with instantaneous reproduction of the pictures in a permanent format by ground-based facsimilie recorders.

The Nimbus 1 APT system makes cloudcover data from satellites available to local users by eliminating the problems arising from retransmission of pictures, elaborate communications equipment and networks, and communications delays.

The instrumentation composing the APT system is of two kinds.

Satellite-Borne Equipment

The APT equipment carried on a satellite (Figure 5) consists of optics, including the shutters; an 800-scan-line 1-inch-diameter electrostatic storage vidicon; vidicon electronics, video circuitry, an AM modulator, and a 5-watt FM transmitter. The vidicon camera, on the

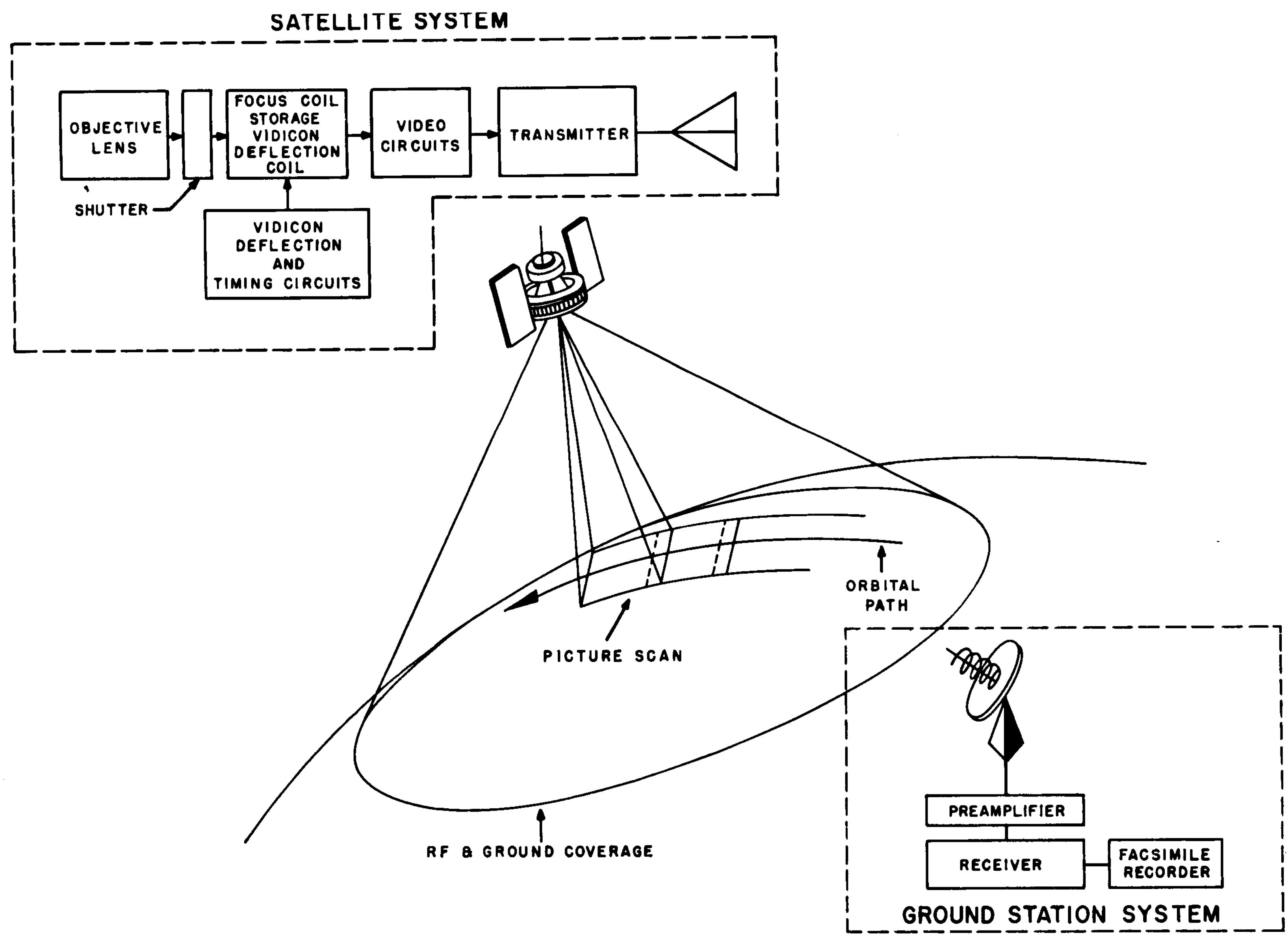

Figure 5. Automatic Picture-Transmission System

bottom of the H-frame along with the APT transmitting antenna, always faces the earth.

The camera takes pictures continuously throughout the sunlit portion of each orbit. Each picture covers a ground area of approximately 1050 by 1050 nautical miles, with a north-south overlap of 300 nautical miles between adjacent pictures (Figure 6). A 108-degree Tegea lens focuses the camera's field-of-view on the vidicon. The picture, stored electrically on a polystyrene layer in the vidicon during the first 8 seconds of every picture sequence, is read out line by line during the next 200 seconds at a picture-scanning rate of 4 lines per second and transmitted to the APT ground stations. Start and phasing signals transmitted to the ground stations at the beginning of each picture synchronize the ground-station facsimile recorders with the vidicon-scanning beam. Figure 7 shows schematically the geometric relations of the camera orientation, and Table 1 lists the nominal optical values of the APT.

Table 1

APT Optics

Item	Nominal Value
Focal length (f-number)	5.6 mm (f/1.8)
Field-of-view	108 degrees
Illumination at f/18 at 50 degrees	Half-angle, 22 percent

The video circuitry produces a continuous analog readout which amplitude-modulates a 2400-cps subcarrier. This in turn frequency-modulates the FM transmitter for transmission over a narrow bandwidth of 136 Mc to the ground stations.

Ground-Station Equipment

The APT ground stations are relatively simple and inexpensive units suitable for wide distribution and use by the United States Weather Bureau, meteorological services of the United States Armed Forces, and other meteorological groups throughout the world. An APT ground station (shown in Figure 5) consists of four basic components: the antenna, preamplifier, receiver, and facsimile recorder.

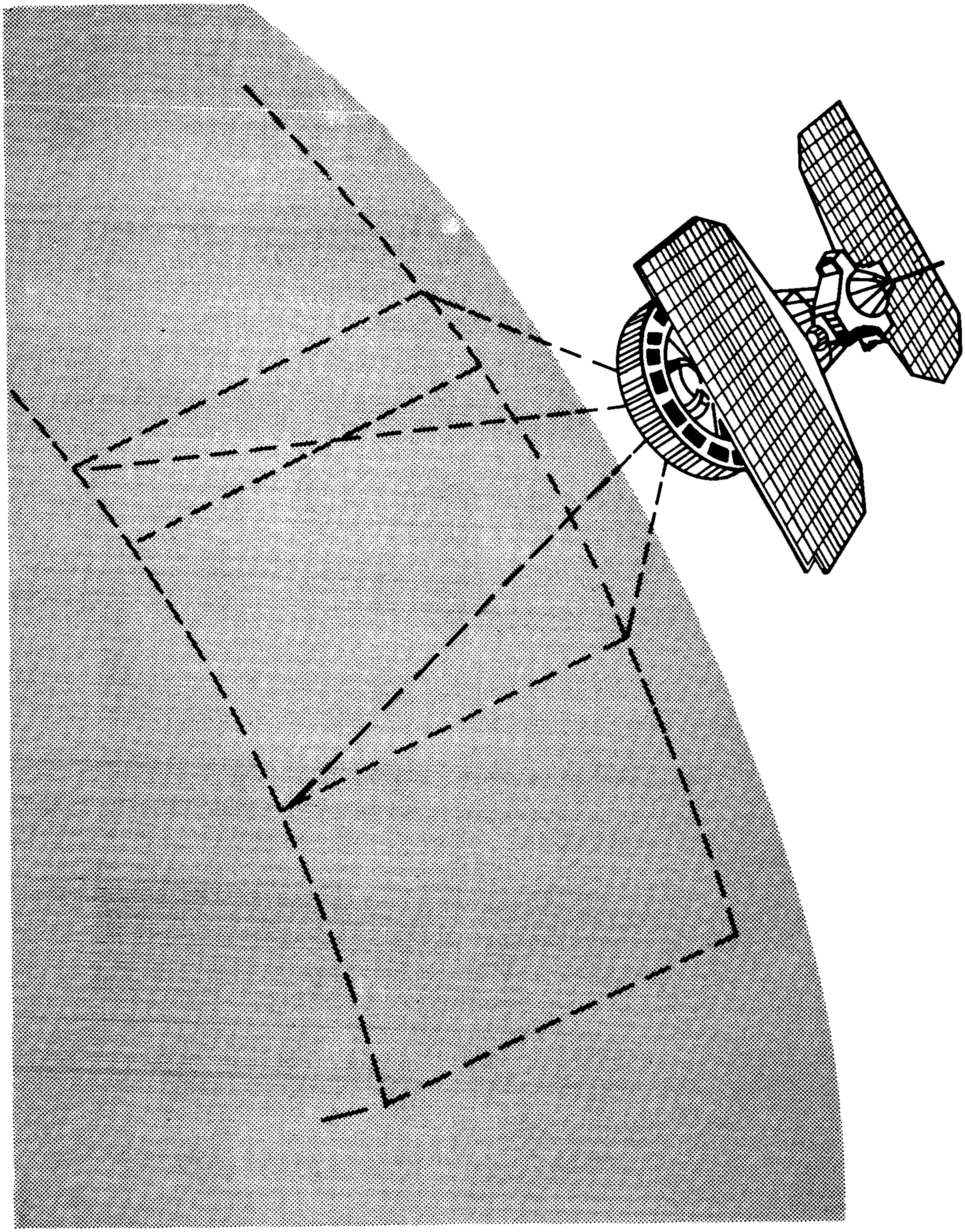

Figure 6. APT Picture Coverage

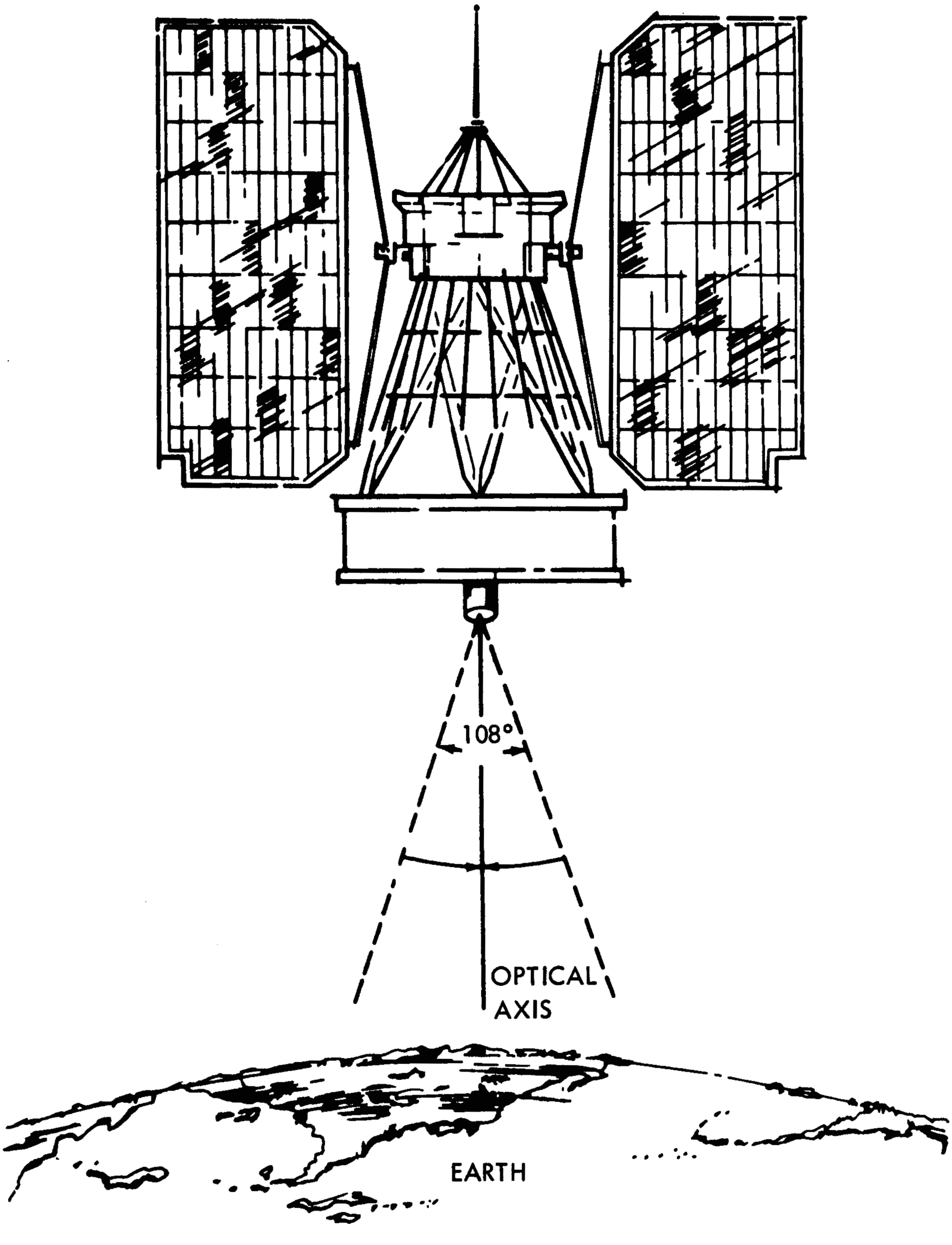

Figure 7. APT Camera Optics Schematic

The antenna (Figure 8) is a pedestal-mounted 8-turn helix. The antenna drive system is capable of ±360-degree rotation from the center point in azimuth, and 180-degree rotation in elevation. Position-control and indicator units in the ground-station console (Figure 9) permit independent rate control of both azimuth and elevation and continuous display of antenna position.

A preamplifier, mounted on the antenna pedestal, is an RF amplifier with a 22-db gain which can compensate for losses in the RF cable (up to 1000 feet) between the antenna and receiver.

The frequency of an FM receiver in the ground-station console, is selectable from 130 to 140 Mc by means of crystal substitution. A vernier control allows tuning across a 150-kc band on either side of the selected operating frequency.

The receiver includes both aural and visual means of determining the presence and condition of the input signal. A speaker provides aural indication of signal presence; indicators provide a visual check on signal strength, tuning, video output, and frequency deviation.

A facsimile recorder in the ground-station console forms a picture, line by line, by depositing ions on wet electrosensitive paper. The recorder operates at 240 rpm with a resolution of 100 lines per inch. The unit will produce ten shades of gray varying from black to white. The picture has an aspect ratio of 1 on an 8- by 8-inch format.

The unit either will start and phase automatically (upon receipt of start and phasing signals from the spacecraft), or can be started and phased manually. The latter capability permits an operator to obtain picture information when the spacecraft is acquired after the start of a picture cycle.

PICTURE ANALYSIS

In addition to the 88 frames of facsimile pictures recorded by the APT ground station at GSFC, Nimbus 1's video signal was also recorded on an Ampex PR-10 magnetic tape recorder, and the resulting tapes were used as an aid in picture analysis. More than 260 oscilloscope pictures were taken of the taped video signals. Although oscilloscope pictures were not taken of every frame, each facsimile picture was examined to note any apparent change in APT camera performance.

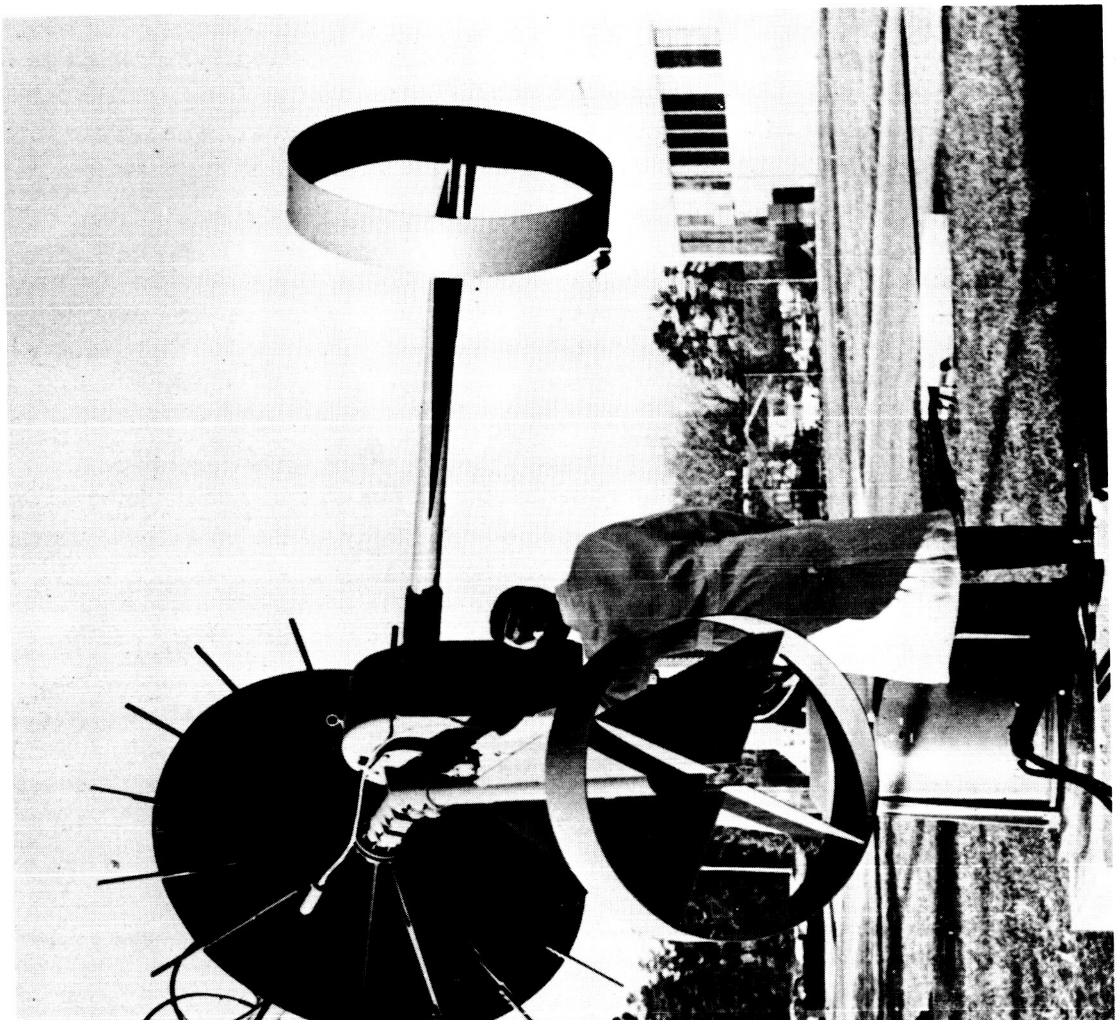

Figure 8. APT Antenna

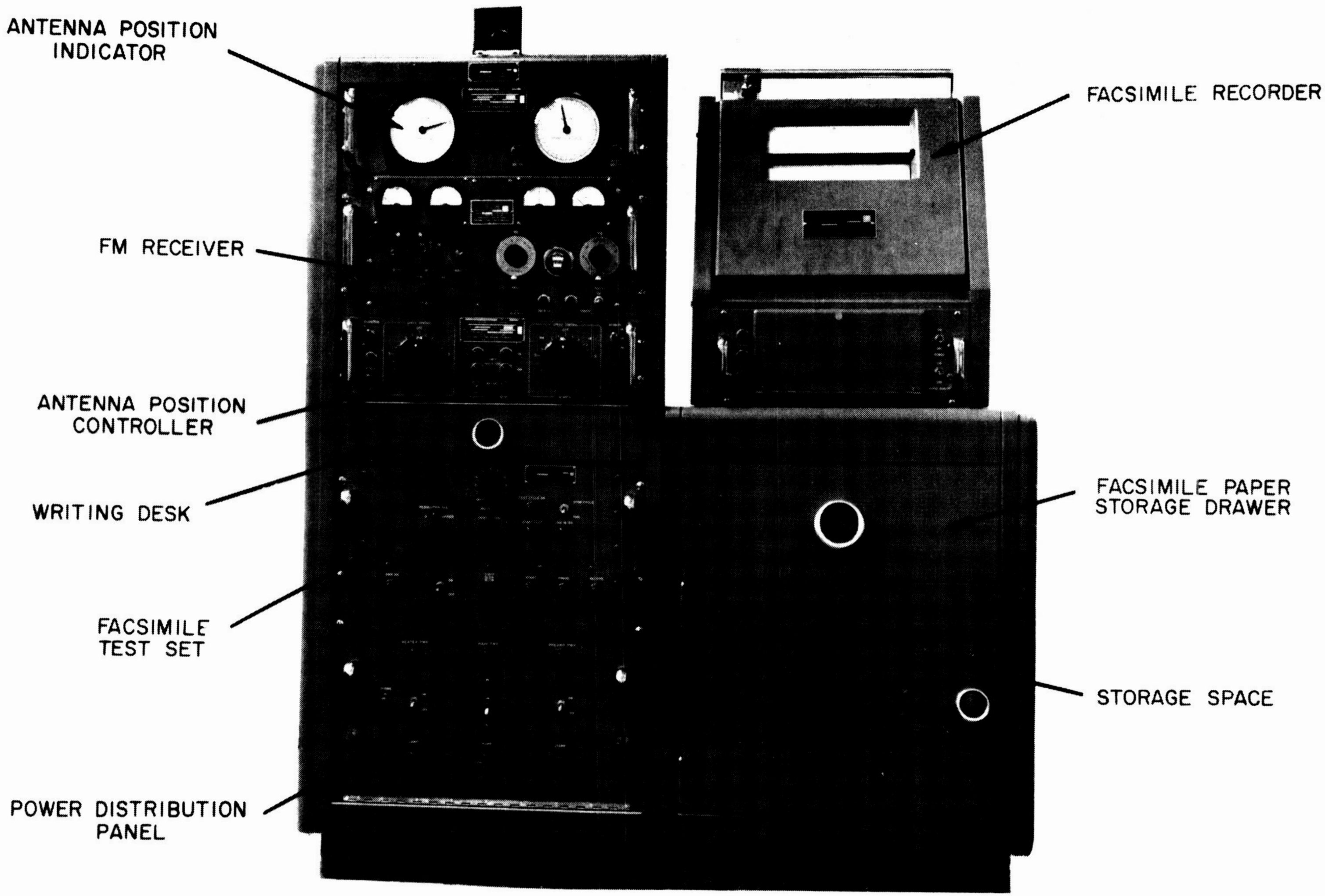

Figure 9. APT Ground-Station Console

Parameters under study included the dynamic range (black/white ratio) using the phasing bar as a reference, and the picture resolution using the width of the fiducal* as a reference. Data were not tabulated where a high noise or low antenna elevation was encountered.

Dynamic Range

The video white level maintained average level (i.e., peak scene white level) in relation to the phasing-bar white during the lifetime of Nimbus 1. The black level became less black for the first few orbits, and the average level remained fairly constant throughout the rest of the satellite's life.

The contrast of the fiducial marks, which should have remained constant throughout the life of Nimbus 1, appeared to degrade rather rapidly at first and then slowly, at times, especially toward the later orbits. The fiducial marks appeared less black than the blackest scene. Large changes in black level and fiducial level from orbit to orbit coincided with each other quite well. The decrease in black level of the fiducial marks is probably an "average-scene brightness" problem associated with the type of vidicon flown on Nimbus 1, arising from a tendency of the vidicon camera to make the dark part of a major white scene appear lighter. Where the majority of the areas are dark, the white areas appear darker.

Picture Resolution

Picture resolution appeared to degrade over the lifetime of the satellite in the order of about 20 to 30 percent. The width of the fiducial was used as a measure of resolution. Values used for measuring fiducial pulsewidths may be equated in inches for graphing convenience. Figure 10 is an example of the graphs which may be obtained. On the vertical axis, one millimeter represents 0.24 inch, the distance between horizontal lines on the facsimile paper. The horizontal axis is plotted in terms of half-cycles per second and equated: 1 half-cycle equals 0.25. The resulting graph represents the fiducial pulse width and may then be calculated in terms of unmodulated area. Figure 11 is a plot of this calculation. Although variations occur from orbit to orbit, the general trend is toward increased area or decreased resolution.

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*Fiducial - a calibration mark etched into the camera lens and reproduced on the resulting pictures as a point of reference

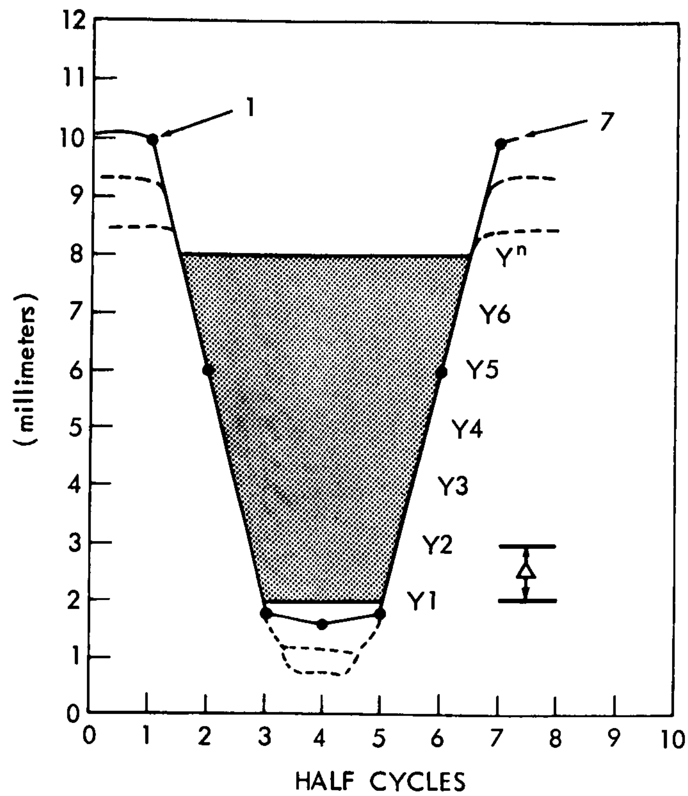

Figure 10. Graph of Fiducial Pulsewidth

An aspect ratio of one to one was maintained during the satellite life. Shading, which is noticable to some extent on all pictures, did not appear to change significantly. When viewing a picture with the start and phase tones at the top, the area in the lower right and left show shading in all pictures. Some shading appears to the right of the phasing bar in most, but not all, pictures.

APT RESULTS FROM NIMBUS 1

Blanks in the orbit sequence represent times when the APT was not turned ON (Orbits 93 and 94), or when it was turned ON and no video was received (Orbits 64, 65, 78, and 79). Tapes 64, 65, 28, and 29 do show a start tone and phasing signal, but then a very high-level carrier with no video. Carrier deviation during this period was about 15 kc, as opposted to the normal 8 to 10 kc. This same problem appeared on the TIROS 8 APT system (see orbit 2179, 19 May 1964).

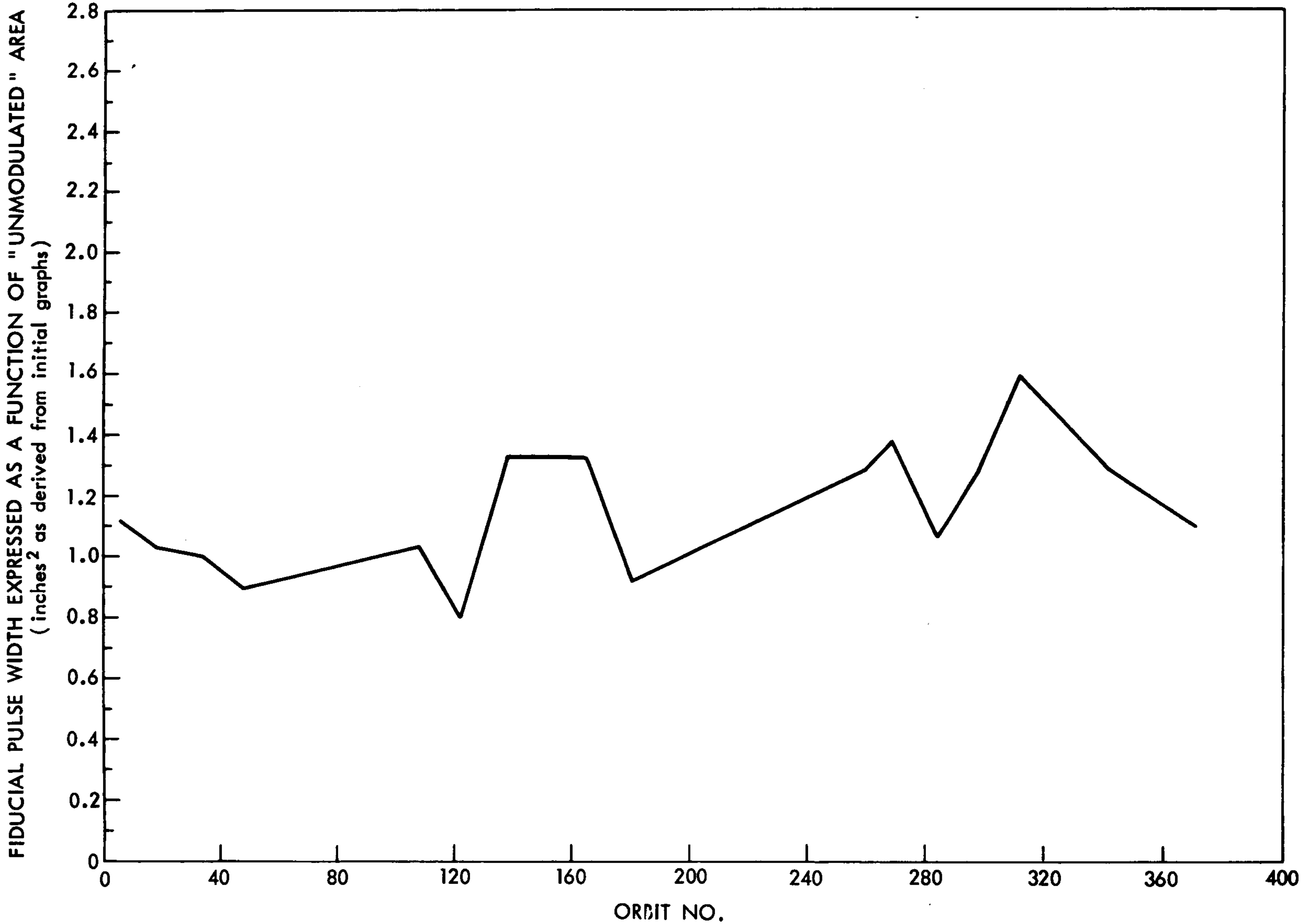

Figure 11. Variation of Picture Resolution vs. Orbits During Useful Life of Nimbus 1

In some orbits, as many as four frames were recorded, but oscilloscope pictures of only one frame were photographed. An effort was made here to select the frame that would show a black-and-white saturated level. The other frames in these orbits were checked by observing the video on the oscilloscope to see if there had been any significant changes in saturated level. If a change occurred, pictures were made; if there were no changes, only one frame was used.

Figures 12 through 15 are oscilloscope pictures of the phasing bar, fiducial marks, and scene white that generally might be expected; that is, phasing bar as maximum white, scene white a bit below, and fiducial marks as minimum signal. The phasing bar should represent maximum signal or white, and the fiducial marks minimum signal or black. The phasing signal, which does not depend on the view seen by the camera but is generated electronically, would make an ideal reference for maximum signal. The fiducial marks, etched on the face of the vidicon tube, would remain constant in level and width and furnish a minimum signal level. The video signal would fall somewhere in between, depending on the amount of cloudcover the camera sees.

The oscilloscope picture in Figure 12, from orbit 19 frame 3, was taken 5-3/8 inches from beginning of the start tone. It shows the maximum scene white in relation to the phasing bar. Frame 3 is shown, and the area of the oscilloscope picture is marked. The pictures in Figure 13, taken from orbit 6 frame 1, show the fiducial as minimum signal or black. Figure 13a shows scene black and is close to the fiducial black. These are the expected values. The Figure 14 oscilloscope pictures, taken from orbit 209 frame 2 and orbit 297 frame 3, show the fiducial level as greater than scene black. The complete frame shows a variation of many fiducials in this readout.

Although the average white level of a frame is a function of the scene and will change, the peak white level from frame to frame should bear a close relationship to the white phasing bar; i.e., peak scene white below phasing white. In an effort to get the maximum white area of a scene, facsimile readouts were taken and the frame examined (Figure 15).

Any loss of resolution can be estimated by using the fiducial marks etched on the camera faceplate as a reference. Any increase in the time or number of cycles of the 2400-cps carrier of this fiducial mark indicates reduced camera-system resolution.

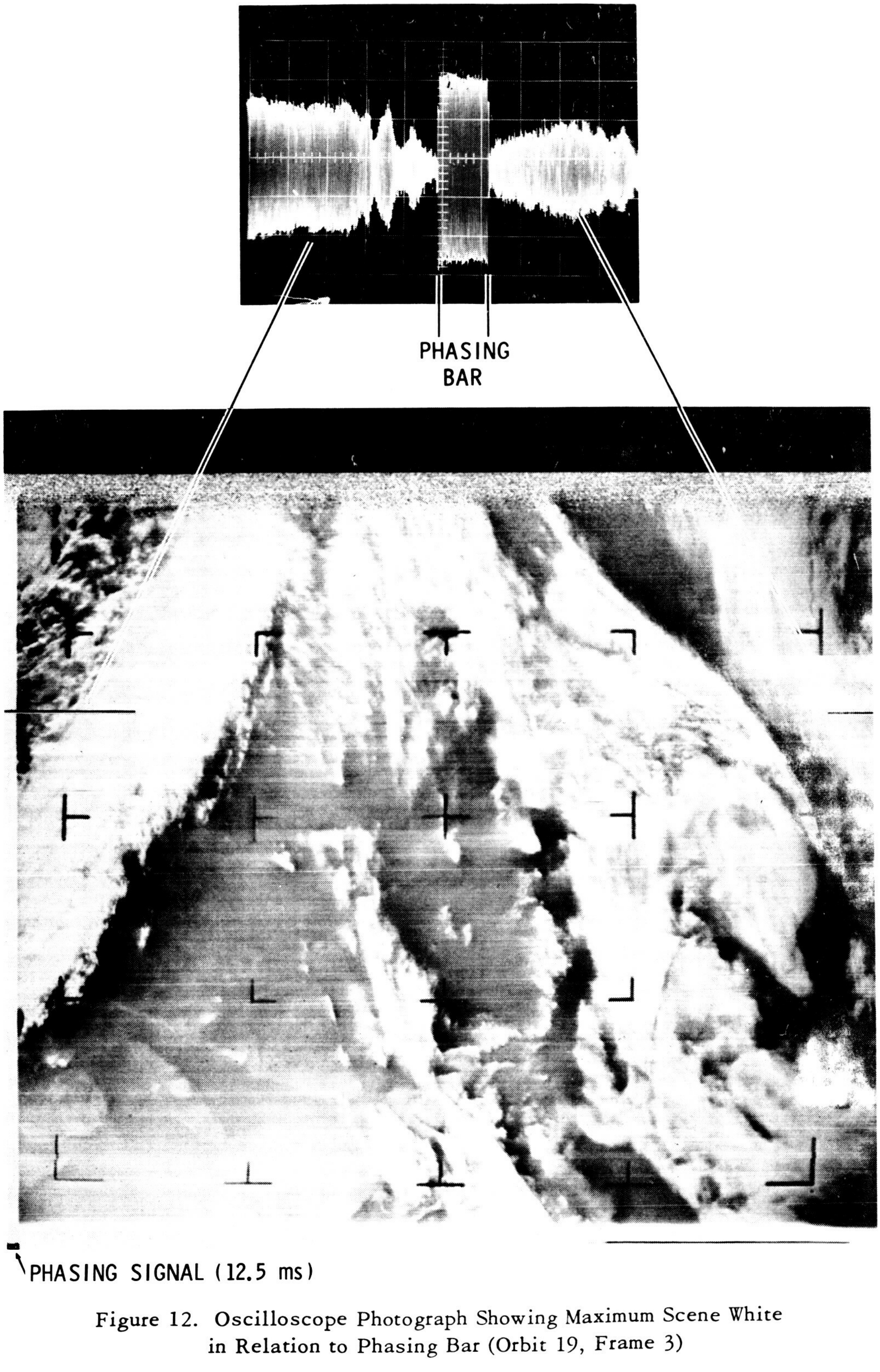

Figure 12. Oscilloscope Photograph Showing Maximum Scene White in Relation to Phasing Bar (Orbit 19, Frame 3)

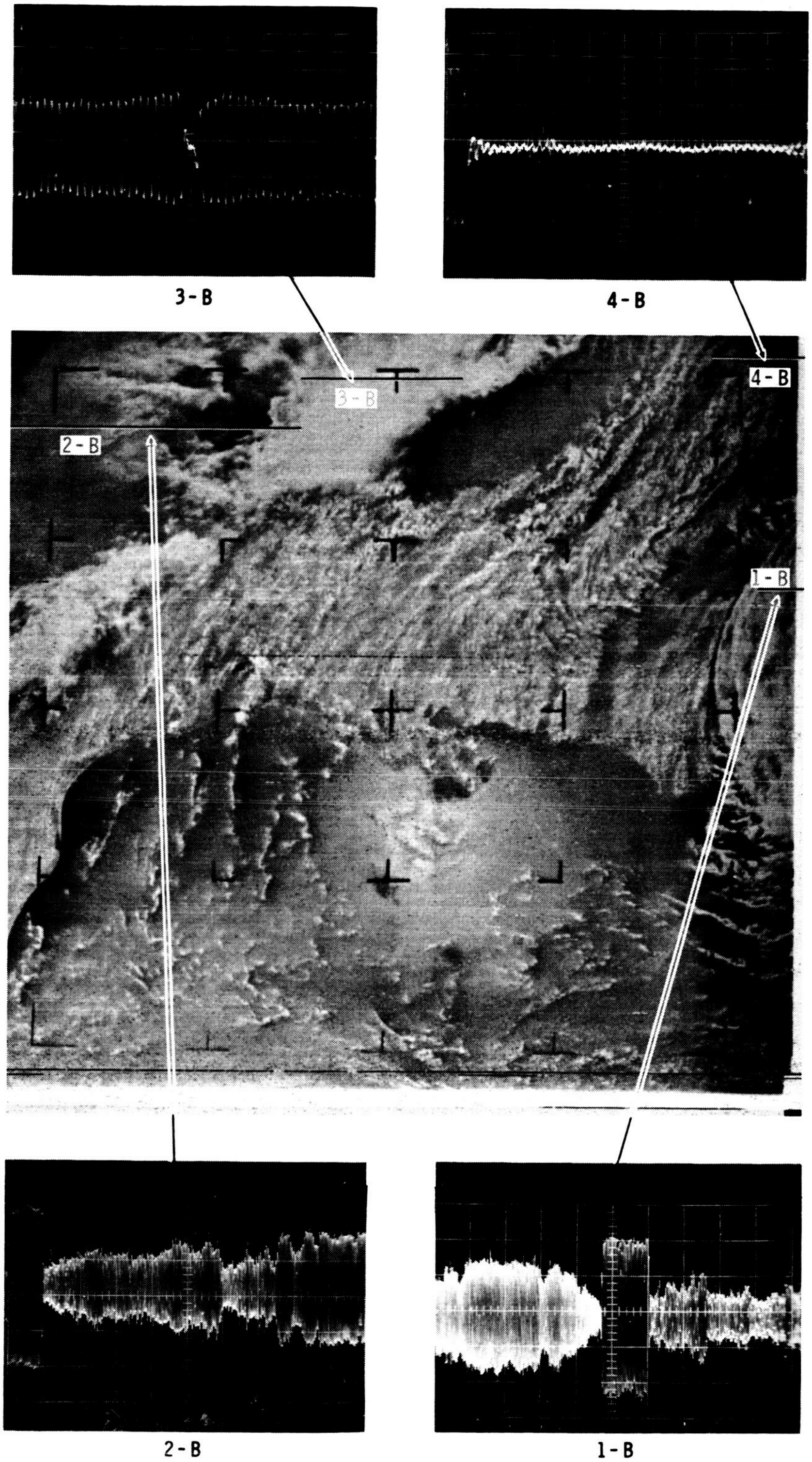

Figure 13. Oscilloscope Photographs Showing the Fiducial Level as Minimum Signal or Scene Black (Orbit 6, Frame 1)

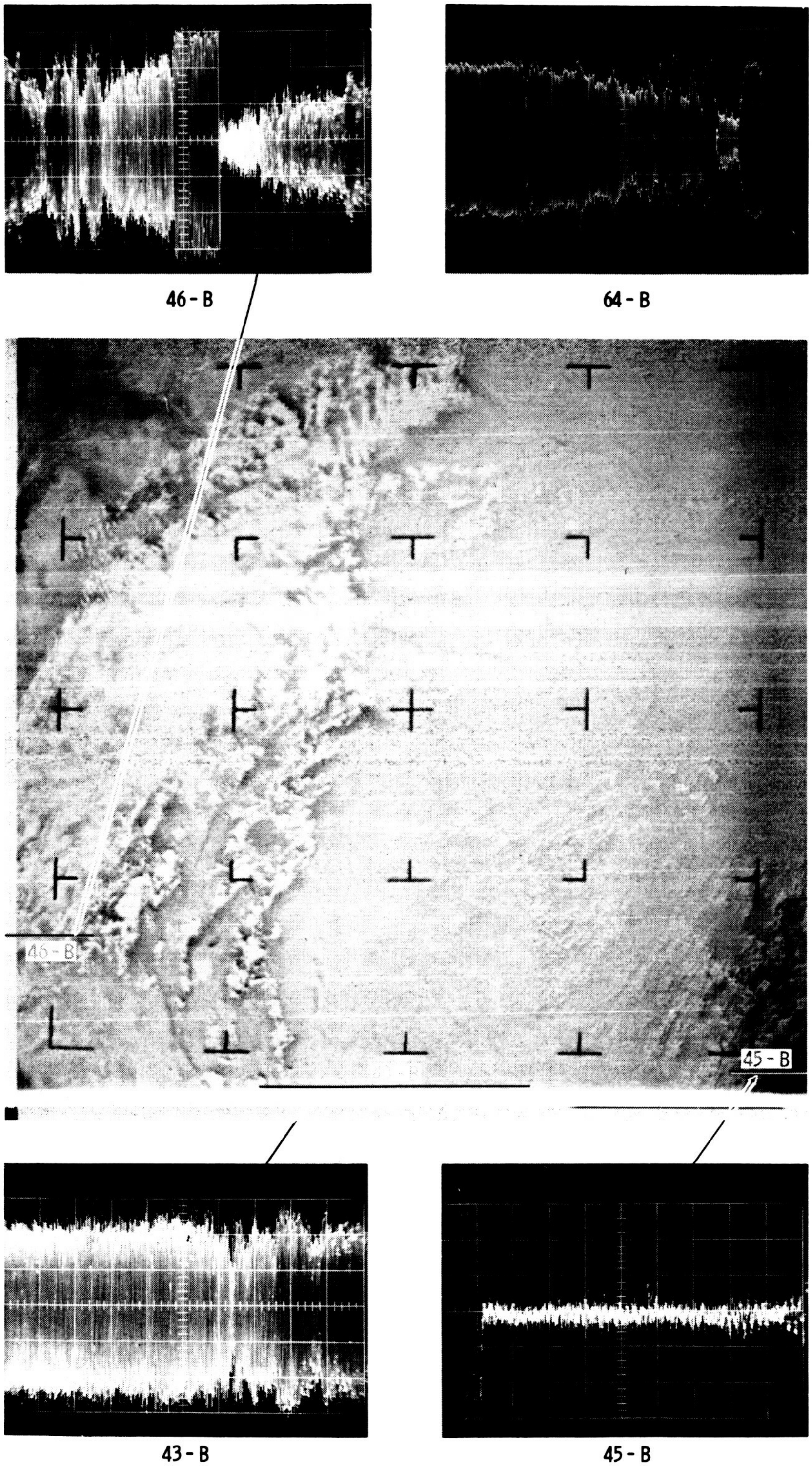

Figure 14. Oscilloscope Photographs Showing Fiducial Level as Greater Than Scene Black (Orbit 209, Frame 2; Orbit 297, Frame 3)

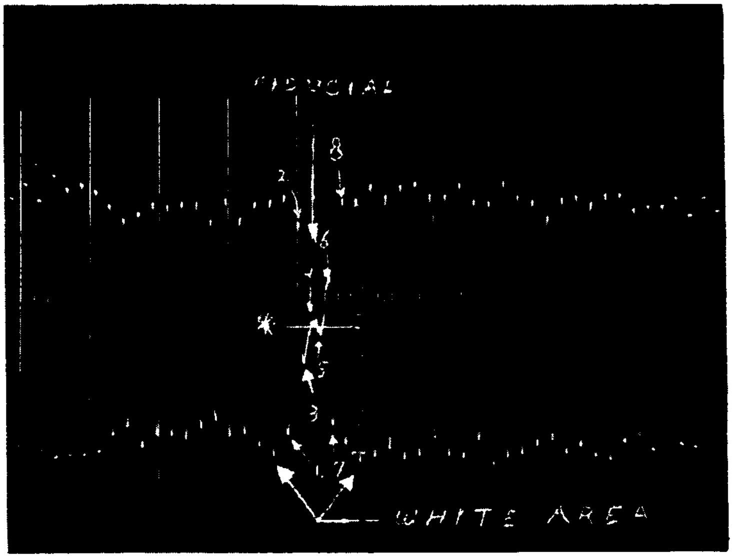

Figure 15. Oscilloscope Photograph of Facsimile Readout
Showing Fiducial Marks and Scene White Area

Comparison of various portions of the subcarrier containing the fiducial marks in different orbits reveals a relative change in fiducial pulsewidth in terms of half-cycles per second, as recorded on the corresponding Polaroid pictures. These half-cycles are measured in peak values, starting from the white area, through the fiducial, and ending in the next white area. The measurement is in terms of millimeters, the scale appearing on the Polaroid picture. The zero level, or reference level, is the midpoint level of the subcarrier. The measurements, made from left to right, include the peak values of each half-cycle above and below the reference line.

The dot-dash line in Figure 16 indicates the video white level, the whitest part of the picture as referred against the white of the phasing bar. The white level remains fairly constant throughout the satellite lifetime. Data are available which show the location of the areas in which the Polaroid pictures were taken.

The solid line on the graph, which is the maximum scene-black level of the video as referenced against the phasing bar, may change from frame to frame because of light-level changes, average cloud-cover, etc., as the satellite traverses the earth. When dramatic changes appeared, more than one frame was studied to see if a trend was developing. The first few orbits appear to show a gradual graying on the black level, then a general leveling-off.

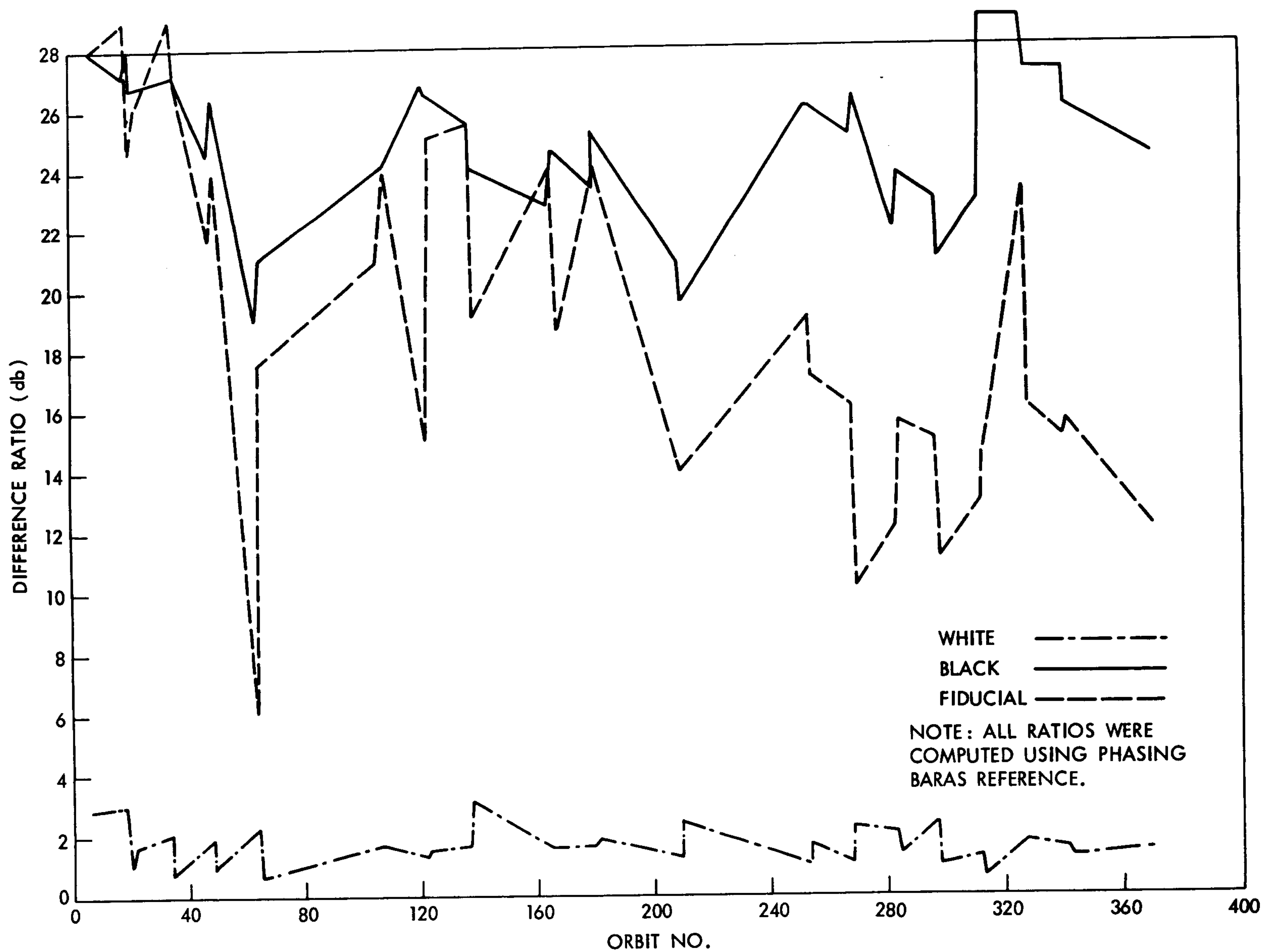

Figure 16. APT Picture-Element Ratio vs. Orbits During Useful Life of Nimbus 1

To obtain dynamic range, it is necessary only to observe the difference in the dot-dash and solid lines. Generally, after the first few orbits, the dynamic range was constant.

The fiducial black level, which should remain constant, was also plotted against the phase far white. This is shown by the dotted line. The method here was to pick a fiducial in the white part of a frame and note the difference in level between the fiducial and the phase bar. Orbit 64 shows a great change in this level; in this orbit, no complete pictures were received. In immediately preceding orbits (65, 78 and 79), only a white level with no video or very little video (65) was received.

METHOD OF MEASUREMENT

The block diagram (Figure 17) shows the method used for measuring the parameters of Nimbus 1's APT signals. The steps used to perform the measurements are:

1. The facsimile-recorder START amplifier sensitivity potentiometer was turned full counterclockwise to prevent operation of the automatic START circuitry and phasing circuitry.

2. The leads from the helix drum switch (S1201) were disconnected and used in conjunction with 4.5-volt battery to furnish a dc sync pulse to the external trigger input to a Tektronix 535 oscilloscope.

3. Video output from Channel 2 of the PR-10 recorder was fed to the facsimile test set and to the signal input of the oscilloscope. The test set was used to divide the 2400-cps video by 20.

4. The facsimile recorder was operated in "EMERGENCY" mode to divide the 120-pps output of the test set by two, and thus furnish the nominal 60-cps power for the helix drum motor.

5. Specific portions of the 250-ms video line were positioned on the oscilloscope grid by operating the manual-phase button on the facsimile recorder.

6. A Polaroid Land camera with ASA 3000 10-second development file was used. The shutter was operated in the BULB position at F8 opening. The oscilloscope was set to single-trace operation.

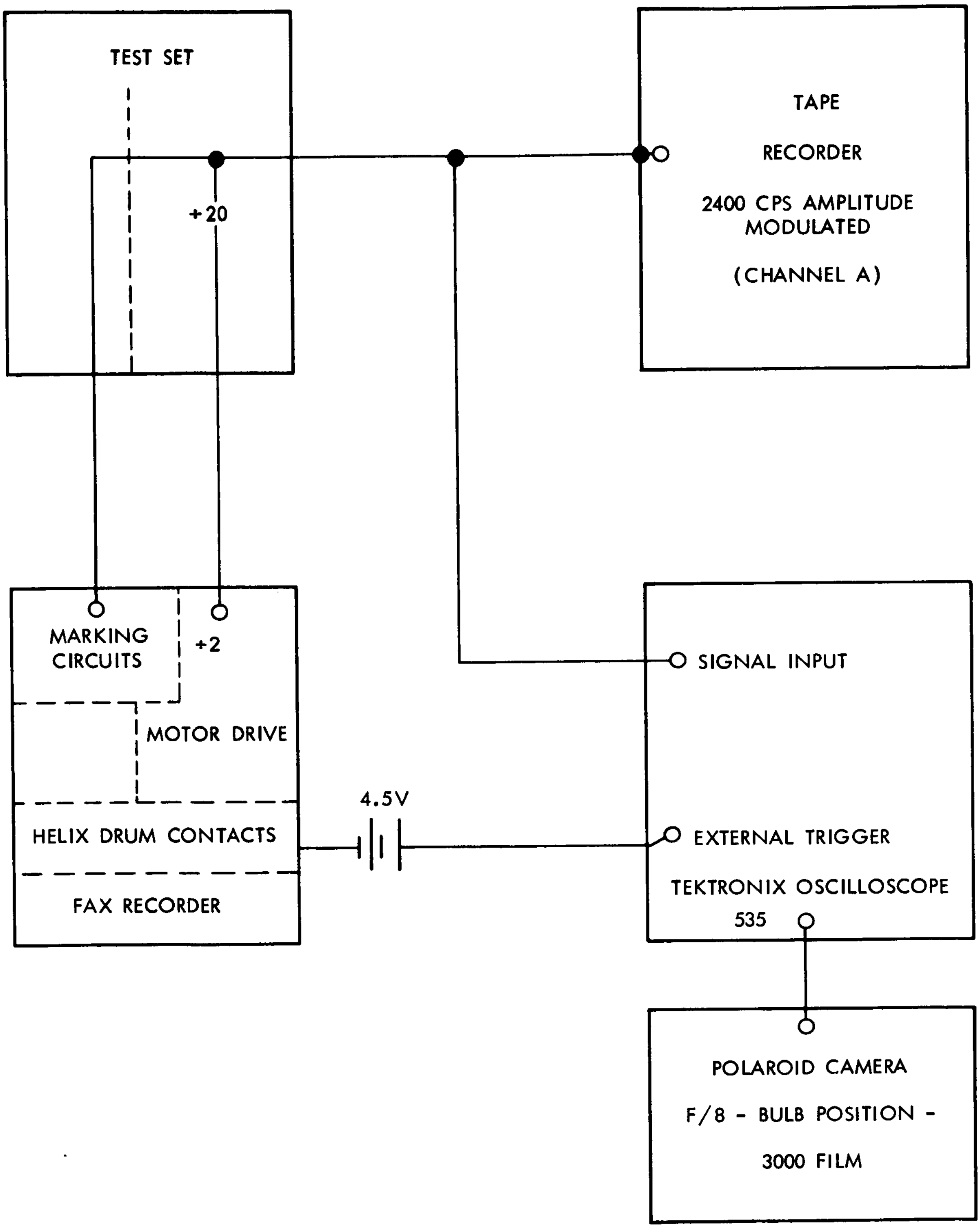

Figure 17. Method of Measurement, Block Diagram

7. Observation of the video on the facsimile recorder served to synchronize video and camera operation.

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